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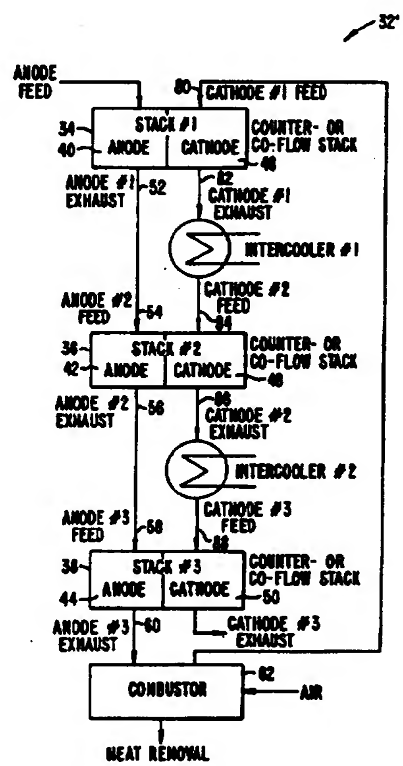
(54) Title: THERMAL INTEGRATION OF AN AIR-COOLED FUEL CELL STACK

(57) Abstract

The invention provides a molten carbonate fuel cell system having a plurality of fuel cell stacks (34, 36, 38) with each fuel cell stack having an anode (40, 42, 44) and a cathode (46, 48, 50). Each of the anodes includes a cathode feed inlet and a cathode exhaust outlet. A combustor for receiving unreacted fuel from the anode exhaust outlet of a first one of the fuel cell stacks (60) is connected to the cathode feed inlet of a second one of the fuel cell stacks (80) for delivering exhaust from the combustor. An intercooler is disposed between the cathode exhaust outlet of the second fuel cell stack (86) and the cathode feed inlet of the first fuel cell stack (88) for cooling gases passing therebetween.



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THERMAL INTEGRATION OF AN AIR-COOLED FUEL CELL STACK

BACKGROUND OF THE INVENTION

The invention is related to fuel cell systems that utilize gas recirculation for fuel cell stack temperature control, and in particular to molten carbonate fuel cell (MCFC) systems.

A fuel cell consists of two distinct reacting chambers commonly referred to as the anode and cathode. Fuel cell systems are constructed of multiple fuel cells operating in parallel and connected electrically in series. The multiple fuel cells are typically combined into one operating unit with the appropriate gas manifolding to form what is commonly referred to as a fuel cell stack.

Fig. 1 illustrates a schematic view of a conventional MCFC system 10. In the MCFC system 10, reformed fuel is delivered to an anode 14 of a fuel cell stack 16 through an anode feed inlet 12 where it reacts with carbonate ions to produce carbon dioxide, water, and electricity. Typically, 70% to 85% of the fuel heating value is consumed in the anode 14. Downstream from the anode 14, the remaining unreacted fuel is delivered to a combustor 18 through an anode exhaust outlet 20. The unreacted fuel is burned in the combustor 18 to produce carbon dioxide and water. Oxygen is supplied to the combustor 18 and may be either air and/or cathode exhaust gases. Various heat integration schemes have been proposed for recuperating both the heat in the cathode exhaust and the heat liberated in the combustor 18 for various purposes such as preheating, steam generation, and supplying the heat required for reforming fuel. The combustor exhaust is mixed with excess air and sent to a cathode 22 of the fuel cell stack 16 through a cathode feed inlet 24 where carbon dioxide and oxygen are reacted to regenerate the carbonate ions consumed at the anode 14.

The overall reaction in the fuel cell stack 16 is that of combustion. Heat is generated in the stack 16 through the heat of reaction of fuel as well as heat generated through ohmic losses. A typical fuel cell system utilizes recirculation of cooled cathode exhaust gases in order to control the fuel cell stack temperature. In some systems, anode gas recirculation is also used. The cathode exhaust gases are recirculated through a cathode exhaust outlet 26 and are directed through a recycle cooler 28. A recycle blower 30 is also used to recirculate the gas. The recycle blower 30 introduces various problems and limitations including decreased reliability, increased maintenance, increased auxiliary power consumption, increased plot space, and increased noise. In addition, recirculation of gases leads to larger gas flows and therefore larger diameter piping between the fuel cell stack 16 and the balance of plant.

SUMMARY OF THE INVENTION

According to the invention, a MCFC system is provided having a plurality of fuel cell stacks. Each fuel cell stack includes an anode and a cathode, with each anode having an anode feed inlet and an anode exhaust outlet, and each cathode having a cathode feed inlet and a cathode exhaust outlet. The system includes a combustor for receiving unreacted fuel from the anode exhaust outlet of a first one of the fuel cell stacks. The combustor is connected to the cathode feed inlet of a second one of the fuel cell stacks for delivering exhaust from the combustor to the second fuel cell stack. An intercooler is provided between the cathode exhaust outlet of the second fuel cell stack and the cathode feed inlet of the second fuel cell stack for cooling gases passing therebetween.

In another embodiment, a MCFC system is provided having a plurality of fuel cell stacks with each fuel cell stack having an anode and a cathode. Each anode includes an anode feed inlet and an anode exhaust outlet, and each cathode includes a cathode feed inlet and a cathode exhaust outlet. A combustor is provided for receiving the reacted fuel from the

anode exhaust outlet of a first one of the fuel cell stacks. The combustor is connected to the cathode feed inlet of the first fuel cell stack for delivering exhaust from the combustor. An intercooler between the cathode exhaust outlet of the first fuel cell stack and the cathode feed inlet of a second fuel cell stack is provided for cooling gases passing between the fuel cell stacks.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates a schematic view of a conventional MCFC system.

Fig. 2 illustrates one embodiment of a MCFC system according to the present invention.

Fig. 3 illustrates an alternative embodiment of a MCFC system according to the present invention.

Fig. 4 illustrates a plant configuration using a MCFC system according to the present invention.

DETAILED DESCRIPTION OF THE SPECIFIC EMBODIMENTS

Shown in Fig. 2 is one embodiment of a MCFC system 32 according to the invention. The system 32 includes three fuel cell stacks 34, 36, and 38. Although three fuel cell stacks are illustrated, the number of stacks in the system can be varied depending upon the cost and operability.

Each of the stacks 34, 36, and 38 have an anode 40, 42, 44, respectively, and a cathode 46, 48, and 50, respectively. Gases from the anode 40 pass through an anode exhaust outlet 52 and enter into anode 42 through an anode feed inlet 54. In a similar manner, gases from anode 42 exit through exhaust outlet 56 and enter anode 44 through anode feed inlet 58. Gases are exhausted from anode 44 through an anode exhaust outlet 60 and into a combustor 62.

Countercurrent to the gasses delivered through the anodes 40, 42, 44, gases are passed through each of the cathodes 50, 48, and 46. Gases from the combustor 62 are enter the cathode 50 through a cathode feed inlet 64. Exhaust from cathode 50 exits through a cathode exhaust outlet 66 and enters cathode 48 through a cathode feed inlet 68. In a

similar manner, gases from cathode 48 are exited through cathode exhaust outlet 70 and pass into cathode 46 through cathode feed inlet 72. With this arrangement, the anode and cathode gases pass countercurrently between the three stacks 34, 36, and 38 as indicated by the arrows in Fig. 2. Within each of the stacks 34, 36, and 38, the anode and cathode gases may flow either countercurrently or co-currently, depending on the preferred operating conditions for the stacks. Disposed between the stack 38 and the stack 36 is an intercooler 74 for cooling the gases exhausted from cathode exhaust outlet 66. Another intercooler 76 is disposed between the stack 36 and the stack 34 to cool gases exhausted through cathode exhaust outlet 70.

By configuring the stacks 34, 36, and 38 in this manner, the use of a recycle blower can be eliminated. Elimination of the recycle blower leads to a variety of benefits including: increased reliability, decreased maintenance, decreased auxiliary power consumption, decreased plot space, decreased noise, and smaller diameter pipes between fuel cell stacks and the balance of plant. Another benefit of multiple fuel cell stacks is that the total electrical power increases with the number of stacks.

An alternative embodiment of a MCFC system 32' is shown in Fig. 3. The system 32' is constructed essentially identically to the system 32 of Fig. 2 except for the flow of gases between the cathodes 46, 48, and 50 and the connection of the combustor 62. Gases from the combustor 62 are directed into the cathode 46 through a cathode feed inlet 80, and gases exit from cathode 46 through a cathode exhaust outlet 82 where they enter the cathode 48 through a cathode feed inlet 84. In a similar manner, gases from cathode 48 exit through cathode exhaust outlet 86 and enter the cathode 50 through a cathode feed inlet 88. This configuration allows for the anode and cathode gases to pass co-currently between the stacks 34, 36, and 38. Within the stacks, gases may flow either countercurrently or co-currently.

Calculations were performed to assess the advantages of the invention as described in Figs. 2 and 3 compared to a

conventional system. Table 1 presents a summary of the stack operating conditions for the conventional system, the system 32 (alternative #1), and system 32' (alternative #2). The calculations are based on the following: fixed anode feed, 250 total cells, 80% anode fuel utilization overall, countercurrent flow within each stack, and 70% excess air overall. Within Table 1, stacks #1, #2, and #3 correspond to stacks 34, 36, and 38, respectively.

TABLE 1

COMPARISON OF MULTIPLE CELL STACK ALTERNATIVES

		Conventional	Alternative #1	Alternative #1
Configuration				
Total Cells		250	250	250
Number of Stacks		1	3	3
Number of Cathode Intercoolers		0	2	2
Anode Flow Path		1	1,2,3	1,2,3
Cathode Flow Path		1	3,2,1	1,2,3
Cell Internal Configuration		Counter Flow	Counter Flow	Counter Flow
Anode Feed Steam-to-Carbon		3.5	3.5	3.5
Stack Operating Conditions				
Anode Flow Rates				
Anode #1	lbmol/hr	37.55	37.55	37.55
Anode #2	lbmol/hr		43.46	43.46
Anode #3	lbmol/hr		49.36	49.36
Cathode Flow Rates				
Cathode #1	lbmol/hr	468.83	131.42	149.13
Cathode #2	lbmol/hr		140.28	140.28
Cathode #3	lbmol/hr		149.13	131.42

		Conventional	Alternative #1	Alternative #1
Anode Utilization				
Anode #1	fract		0.2667	0.2667
Anode #2	fract		0.3637	0.3637
Anode #3	fract		0.5716	0.5716
Overall	fract	0.8000	0.8001	0.8001
Cathode Utlization				
Cathode #1	fract		0.4983	0.2495
Cathode #2	fract		0.3326	0.3328
Cathode #3	fract		0.2495	0.4983
Overall	fract	0.7487	0.7487	0.7487
Stack Voltage				
Stack #1	volts/cell	0.706	0.781	0.811
Stack #2	volts/cell		0.756	0.756
Stack #3	volts/cell		0.722	0.682
Stack Power				
Stack #1	kW d.c.		112.2	116.5
Stack #2	kW d.c.		108.3	108.3
Stack #3	kW d.c.		103.3	97.6
Total	kW d.c.	304.1	323.8	322.4
Stack Temperatures				
Anode #1 In	°F	1200	1200	1200
Anode #1 Out	°F	1100	1100	1100
Cathode #1 In	°F	1050	1050	1050
Cathode #1 Out	°F	1290	Not Calc.	1266 Low: Need to Optimize conversion per cell
Anode #2 In	°F		1100	1100

		Conventional	Alternative #1	Alternative #1
Anode #2 Out	°F		1100	1100
Cathode #2 In	°F		1050	1050
Cathode #2 Out	°F		Not Calc.	1282 Close to 1290 °F
Anode #3 In	°F		1100	1100
Anode #3 Out	°F		1100	1100
Cathode #3 In	°F		1050	1050
Cathode #3 Out	°F		Not Calc.	1345 High: Need to Optimize conversion per cell
Stack #1 Anode Compositions				
H2	mole fract.	0.5058	0.5058	0.5058
CO	mole fract.	0.0836	0.0836	0.0836
CO2	mole fract.	0.0669	0.0669	0.0669
H2O	mole fract.	0.3362	0.3362	0.3362
N2	mole fract.	0.0006	0.0006	0.0006
CH4	mole fract.	0.0070	0.0070	0.0070
Total	mole fract.	1.0001	1.0001	1.0001
Stack #2 Anode Compositions				
H2	mole fract.		0.3144	0.3144
CO	mole fract.		0.0591	0.0591
CO2	mole fract.		0.2067	0.2067
H2O	mole fract.		0.4132	0.4132
N2	mole fract.		0.0005	0.0005
CH4	mole fract.		0.0060	0.0060
Total	mole fract.		0.9999	0.9999
Stack #3 Anode Compositions				
H2	mole fract.		0.1677	0.1677
CO	mole fract.		0.0416	0.0416
CO2	mole fract.		0.3121	0.3121

		Conventional	Alternative #1	Alternative #1
H_2O	mole fract.		0.4729	0.4729
N_2	mole fract.		0.0004	0.0004
CH_4	mole fract.		0.0053	0.0053
Total	mole fract.		1.0000	1.0000
Stack #1 Cathode Compositions				
CO_2	mole fract.	0.0901	0.0901	0.1586
H_2O	mole fract.	0.2598	0.2598	0.2290
N_2/Ar	mole fract.	0.5659	0.5659	0.4986
O_2	mole fract.	0.0842	0.0842	0.1138
Total	mole fract.	1.0000	1.0000	1.0000
Stack #2 Cathode Compositions				
CO_2	mole fract.		0.1265	0.1265
H_2O	mole fract.		0.2434	0.2434
N_2/Ar	mole fract.		0.5302	0.5302
O_2	mole fract.		0.0999	0.0999
Total			1.0000	1.0000
Stack #3 Cathode Compositions				
CO_2	mole fract.		0.1586	0.0901
H_2O	mole fract.		0.2290	0.2598
N_2/Ar	mole fract.		0.4986	0.5659
O_2	mole fract.		0.1138	0.0842
Total	mole fract.		1.0000	1.0000

Estimated Pressure Drops

Cell Pressure Drops Proportional to (Flow Rate/Cell (1.5)

Anode #1	Δpsi	0.10	0.52	0.52
Anode #1 to Anode #2	Δpsi		0.05	0.05
Anode #2	Δpsi		0.65	0.65
Anode #2 to Anode #3	Δpsi		0.05	0.05
Anode #3	Δpsi		0.78	0.78

		Conventional	Alternative #1	Alternative #1
Anode #3 to Combustor	Δpsi	0.05	0.05	0.05
Combustor	Δpsi	0.30	0.30	0.30
Combustor to 1st Cathode	Δpsi	0.05	0.05	0.05
1st Cathode	Δpsi	0.60	0.56	0.56
1st Cathode to 1st Intercooler	Δpsi		0.05	0.05
1st Intercooler	Δpsi		0.10	0.10
1st Intercooler to 2nd Cathode	Δpsi		0.05	0.05
2nd Cathode	Δpsi		0.51	0.51
2nd Cathode to 2nd Intercooler	Δpsi		0.05	0.05
2nd Intercooler	Δpsi		0.10	0.10
2nd Intercooler to 3rd Cathode	Δpsi		0.05	0.05
3rd Cathode	Δpsi		0.46	0.46
Total	Δpsi	1.10	4.38	4.38
Estimated Pressure Profile				
Anode #1 Inlet	psia	44.00	44.00	44.00
Anode #1 Outlet	psia	43.90	43.48	43.48
Anode #2 Inlet	psia		43.43	43.43
Anode #2 Outlet	psia		42.78	42.78
Anode #3 Inlet	psia		42.73	42.73
Anode #3 Outlet	psia		41.95	41.95
Combustor Inlet	psia	43.85	41.90	41.90
Combustor Outlet	psia	43.55	41.60	41.60
Cathode #1 Inlet	psia	43.50	40.08	41.55
Cathode #1 Outlet	psia	42.90	39.62	40.99
Intercooler #1 Inlet	psia		40.23	40.94
Intercooler #2 Outlet	psia		40.13	40.84
Cathode #2 Inlet	psia		40.79	40.79
Cathode #2 Outlet	psia		40.28	40.28
Intercooler #2 Inlet	psia		40.94	40.23
Intercooler #2 Outlet	psia		40.84	40.13
Cathode #3 Inlet	psia		41.55	40.08

		Conventional	Alternative #1	Alternative #1
Cathode #3 Outlet	psia		40.99	39.62
Estimated Wet Seal Differential Pressures				
Anode #1 In - Cathode #1 Out	Δpsi	1.10	4.38	3.01
Anode #1 Out - Cathode #1 In	Δpsi	0.40	3.40	1.93
Anode #2 In - Cathode #2 Out	Δpsi		3.15	3.15
Anode #2 Out - Cathode #2 In	Δpsi		1.99	1.99
Anode #3 In - Cathode #3 Out	Δpsi		1.74	3.12
Anode #3 Out - Cathode #3 In	Δpsi		0.40	1.87

These results indicate that gas recirculation is not necessary for stack temperature control. The pressure drop for a three stack system is greater than that of a single stack system. The differential pressures between the anode and cathode side of the stacks can be minimized by using co-flow inside each stack and by using co-flow between the stacks.

The advantages of using multiple fuel stacks does not necessarily require distinct heat exchangers between the cell stacks. The heat removal may be incorporated within the fuel cell manifolding, between or within fuel cell stacks, and from both the anode and cathode gases. In addition, the invention is not limited to the method of stack cooling. Stack cooling may be through indirect heat transfer to cool gases and/or saturated steam or through heat transfer to an "indirect reformer" within the fuel cell stack.

Fig. 4 illustrates one embodiment of a plant configuration 90 utilizing a MCFC system according to the invention. In the plant 90, natural gas is desulfurized in a desulfurizer 92, preheated in a gas preheater 94, mixed with superheated steam from a superheater 96, and further preheated by a mixed feed preheater 98, and sent to a reformer R. An exemplary reformer is a reformer developed by IHI, Japan, where the heat required for reforming is supplied by burning residual fuel that is unconverted in the fuel cell. The

reformed gas is sent to an anode A of a MCFC stack 100 where the majority of the fuel is consumed (via oxidation) to produce electricity. Only a portion of the chemical energy of the reformed gas is converted to electrical energy in the fuel cell. The portion of chemical energy that is not converted to electricity is released as thermal energy (heat). This heat must be removed to avoid the fuel cell exceeding its maximum temperature.

Compressed air from an air compressor 102 provides the necessary cooling medium for heat removal from the stack 100. This is an improvement over the existing state of the art MCFC systems which use recycled cathode exhaust (and in some cases, anode exhaust also) to provide cooling for the fuel cell. In the prior art systems, recirculation of gas requires a recycle blower that operates at temperatures close to 1300°F. Such a blower adds additional expense, consumes electricity, *i.e.*, lowers the plant efficiency, and increases plant downtime due to mechanical failures. Furthermore, large diameter piping is required to provide the necessary path for the recycled gas. The use of air cooling eliminates the need for gas circulation, thereby reducing the plant cost and increasing the overall plant electrical efficiency.

The compressed air exiting the fuel cell intercooler picks up additional energy from flue gas exiting an expander/generator 106, and then flows to a combustor CO. The hot compressed air supplies the oxygen necessary for combustion of the anode exhaust. The combustor exhaust gas flows to the fuel cell cathode C where carbon dioxide and oxygen are consumed. The cathode exhaust gas flows to the expander/generator 106, which recovers some of the energy in the cathode exhaust to produce electricity. The expander exhaust gas provides heat to the compressed air and flows to a heat recovery steam generator (HRSG) 108. The HRSG 108 recovers heat from the processed flue gas for the following purposes: (1) preheating incoming boiler feed water in an economizer 110; (2) generating saturated steam in a boiler 112; (3) heating saturated steam in the superheater 96;

(4) preheating desulfurized natural gas in the gas preheater 94; and (5) preheating mixed natural gas and superheated steam in the mixed feed preheater 98.

Alternative heat integration schemes may employ some or all of the following process options: (1) The use of a turbocharger/generator system in place of a separate air compressor and expander/generator. (2) The placement of the startup burner on the compressed air line between the compressor discharge and the cell intercooler inlet. (This option can eliminate the need for electric startup heaters at the inlet of the fuel cell anode and cathode.) (3) The relocation of the compressed air/flue gas heat exchanger from downstream of the cell intercooler to upstream of the intercooler. This option increases the amount of heat recoverable from the expanding exhaust and increases the temperature of compressed air entering the intercooler (desirable for protecting the fuel cell electrolyte from freezing). This heat exchanger is preferably integrated into the HRSG.

The present invention has been described in detail for purposed of clarity and understanding. It is understood that this invention is not confined to the specific instruction described herein, but it encompasses modified forms within the scope of the following claims.

WHAT IS CLAIMED IS:

1. A molten carbonate fuel cell system, comprising:

a fuel cell having an anode and a cathode, with the anode having an anode feed inlet and an anode exhaust outlet, and with the cathode having a cathode feed inlet and a cathode exhaust outlet, the fuel cell further including an intercooler for channeling the compressed air through the fuel cell;

means for supplying fuel to the anode feed inlet; and

means for supplying compressed air to the heat removal means.

2. The system of claim 1, further comprising means for heating the compressed air prior to entering the heat removal means.

3. The system of claim 2, wherein the heating means includes a heat exchanger for transferring heat to the compressed air from gases circulated from the cathode exhaust outlet.

4. The system of claims 2, further comprising a combustor between the anode exhaust outlet and the cathode feed inlet, and wherein the compressed air is circulated from the fuel cell and to the combustor.

5. The system of claim 4, wherein gases exhausted from the anode exhaust outlet are circulated to the combustor.

6. A molten carbonate fuel cell system, comprising:

a fuel cell having an anode and a cathode, with the anode having an anode feed inlet and an anode exhaust outlet, and with the cathode having a cathode feed inlet and a cathode exhaust outlet, the fuel cell further including heat removal means;

means for supplying fuel to the anode feed inlet;

means for supplying compressed air to the heat removal means; and

a heat exchanger which heats the compressed air prior to entering the heat removal means, said heat exchanger transferring heat to the compressed air from gases circulated from the cathode exhaust outlet.

7. The system of claim 6, further comprising a combustor between the anode exhaust outlet and the cathode feed inlet, and wherein the compressed air is circulated from the fuel cell and to the combustor.

8. The system of claim 7, wherein gases exhausted from the anode exhaust outlet are circulated to the combustor.

9. The system of claim 6, further comprising an intercooler which channels the compressed air through the fuel cell.

10. A process for operating a fuel cell power plant including a combustor and a fuel cell having an anode and a cathode, with the anode having an anode feed inlet and an anode exhaust outlet, and with the cathode having a cathode feed inlet and a cathode exhaust outlet, said process comprising:

supplying fuel to the anode through the anode feed inlet;

circulating exhaust from the anode exhaust outlet, through the combustor, and to the cathode feed inlet; and

supplying compressed air to an intercooler which channels the compressed air through the fuel cell to remove sufficient heat from the fuel cell to prevent overheating of the fuel cell.

11. The process of claim 10, further comprising heating the compressed air prior to supplying the compressed air to the fuel cell.

12. The process of claim 11, wherein the compressed air is heated by gases exhausted from the cathode exhaust outlet.

13. A process for operating a fuel cell power plant including a combustor and a fuel cell having an anode and a cathode, with the anode having an anode feed inlet and an anode exhaust outlet, and with the cathode having a cathode feed inlet and a cathode exhaust outlet, said process comprising:

supplying fuel to the anode through the anode feed inlet;

circulating exhaust from the anode exhaust outlet, through the combustor, and to the cathode feed inlet;

supplying compressed air to the fuel cell to remove sufficient heat from the fuel cell to prevent overheating of the fuel cell, wherein the compressed air is heated prior to supplying the compressed air to the fuel cell, and wherein the compressed air is heated by a heat exchanger receiving gases exhausted from the cathode exhaust outlet.

14. The process of claim 13, wherein the supplying step further comprises channeling the compressed air through the fuel cell with an intercooler.

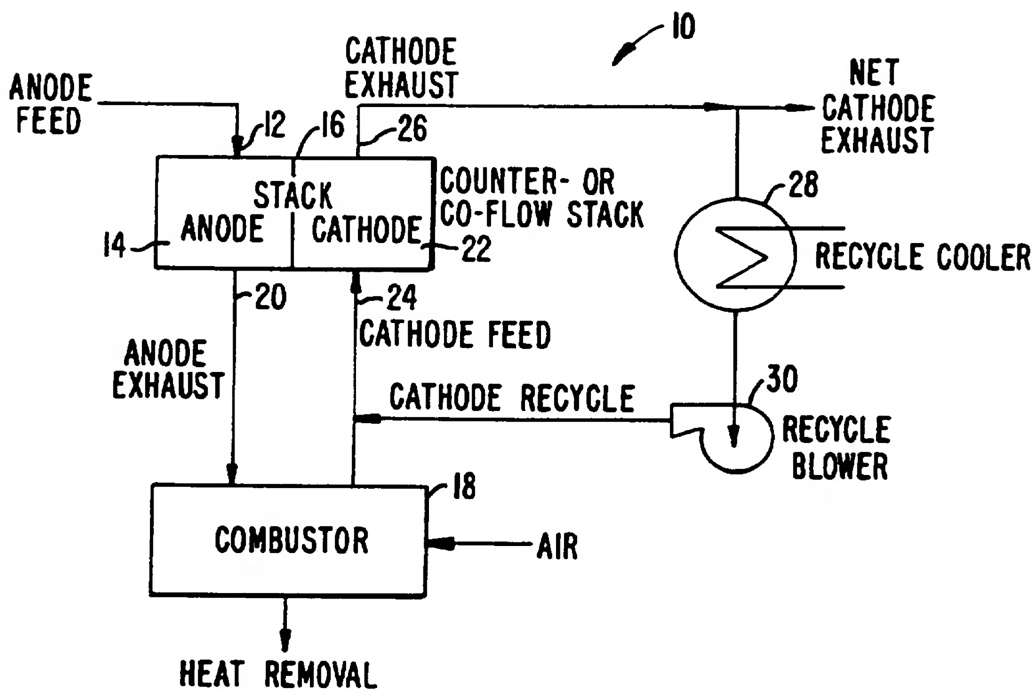
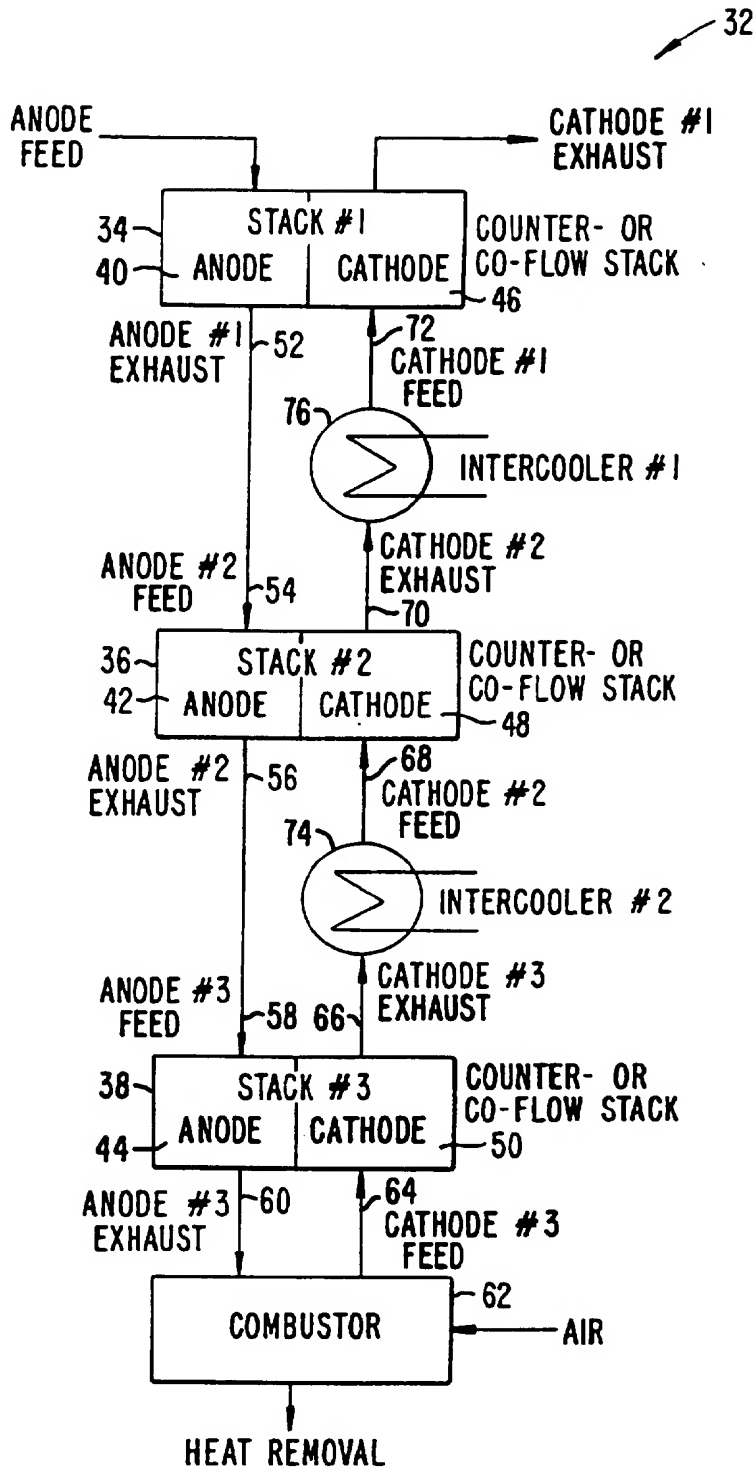


FIG. 1.
PRIOR ART


32
ANODE FEED
CATHODE #1 EXHAUST
STACK #1
34
40
ANODE
CATHODE
COUNTER- OR CO-FLOW STACK
46
ANODE #1 EXHAUST
52
72
CATHODE #1 FEED
76
INTERCOOLER #1
CATHODE #2 EXHAUST
ANODE #2 FEED
54
70
STACK #2
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COUNTER- OR CO-FLOW STACK
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ANODE
CATHODE
COUNTER- OR CO-FLOW STACK
50
ANODE #3 EXHAUST
60
64
CATHODE #3 FEED
62
COMBUSTOR
AIR
HEAT REMOVAL

FIG. 2.

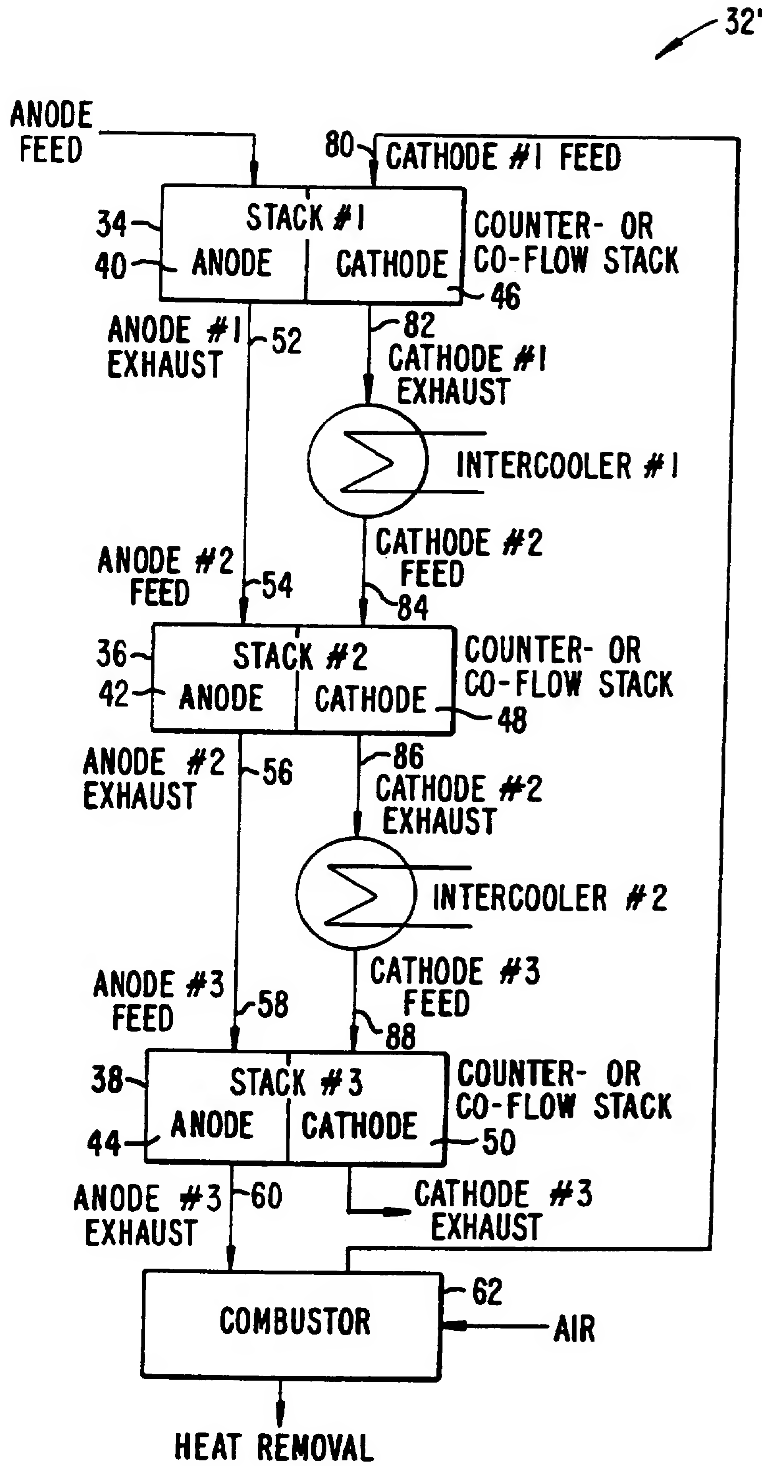
32'
ANODE FEED
80
CATHODE #1 FEED
34
40
STACK #1
ANODE
CATHODE
COUNTER- OR CO-FLOW STACK
46
ANODE #1 EXHAUST
52
82
CATHODE #1 EXHAUST
INTERCOOLER #1
CATHODE #2 FEED
ANODE #2 FEED
54
84
36
42
STACK #2
ANODE
CATHODE
COUNTER- OR CO-FLOW STACK
48
ANODE #2 EXHAUST
56
86
CATHODE #2 EXHAUST
INTERCOOLER #2
CATHODE #3 FEED
ANODE #3 FEED
58
88
38
44
STACK #3
ANODE
CATHODE
COUNTER- OR CO-FLOW STACK
50
ANODE #3 EXHAUST
60
CATHODE #3 EXHAUST
COMBUSTOR
62
AIR
HEAT REMOVAL

FIG. 3.

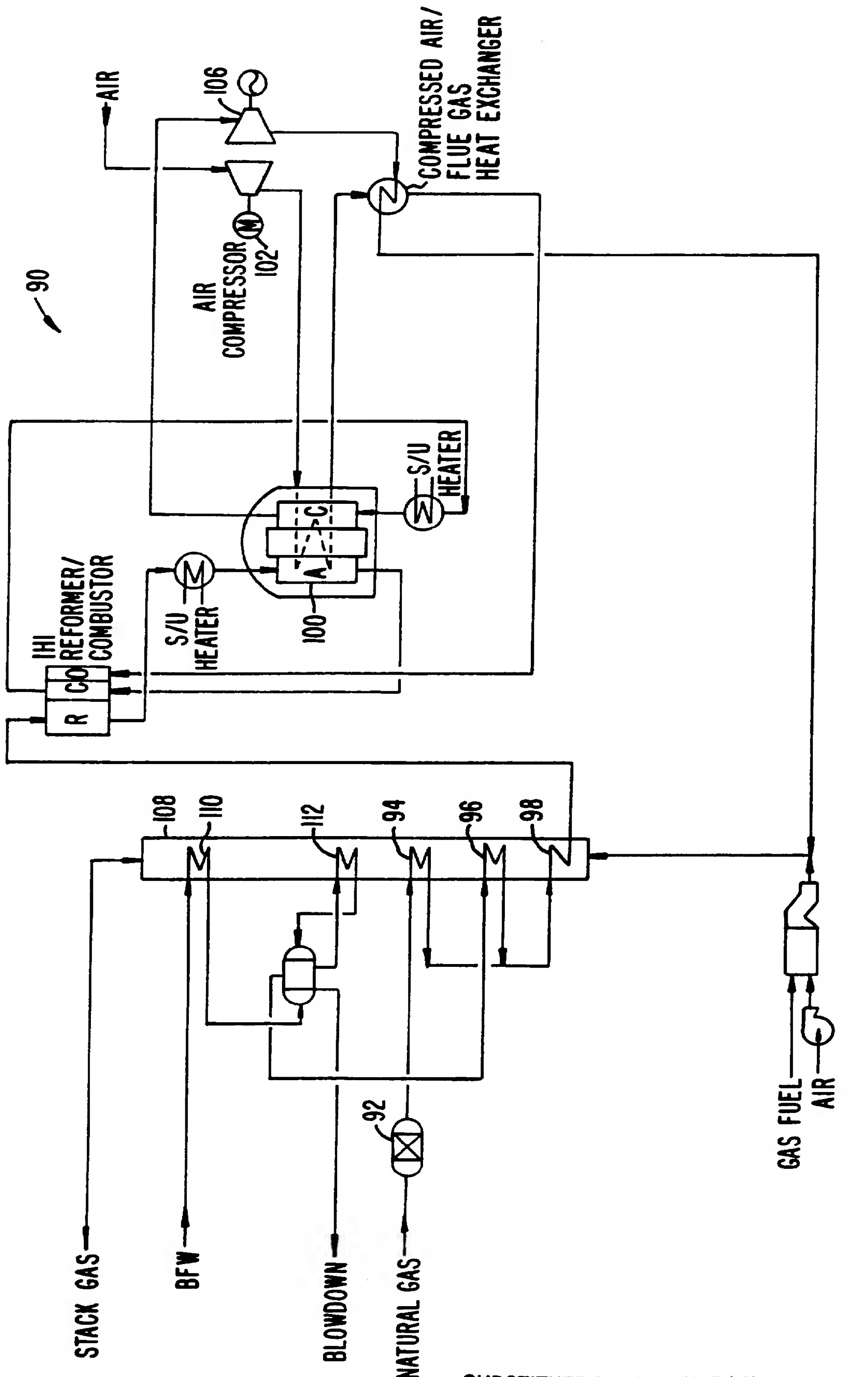
90
AIR
106
AIR COMPRESSOR
102
COMPRESSED AIR/ FLUE GAS HEAT EXCHANGER
S/U HEATER
C
A
100
S/U HEATER
IHI REFORMER/ COMBUSTOR
R
CO
108
110
112
94
96
98
92
STACK GAS
BFW
BLOWDOWN
NATURAL GAS
GAS FUEL
AIR

FIG. 4.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/09184

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H01M 08/04, 08/14
US CL :429/26, 16, 18
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 429/26, 16, 18

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A, P	US, A, 5,413,878 (Williams et al.) 09 May 1995	all
A	US, A, 5,100,743 (Narita et al.) 31 March 1992	all
A	US, A, 4,080,487 (Reiser) 21 March 1978	all
A	US, A, 4,722,873 (Matsumura) 02 February 1988	all

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

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"P" document published prior to the international filing date but later than the priority date claimed

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"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 OCTOBER 1995	03 NOV 1995

Name and mailing address of the ISA/US	Authorized officer
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